Evolution of optical transport networks in Europe: the NOBEL project vision

C. Cavazzoni (1), D. Colle (2), A. Di Giglio (1), G. Edwall (3), G. Eilenberger (4), G. Ferraris (1), H. Haunstein (5), S. Herbst (6), M. Jaeger (7), G. Lehmann (8), J. F. Lobo (9), A. Manzalini (1), S. Santoni (10), M. Schiano (1)
1: Telecom Italia Lab, giuseppe.ferraris@tilab.com; 2: Ghent University, IMEC – IBBT, didier.colle@intec.UGent.be;
3: Ericsson, gunnar.edwall@ericsson.com; 4: Alcatel SEL, Gert.Eilenberger@alcatel.de;
5: Lucent Technologies, hhaunstein@lucent.com; 6: Marconi Ondata, Stefan.Herbst@marconi.com;
7: T-Systems, Monika.Jaeger@t-systems.com; 8: Siemens, gottfried.lehmann@siemens.com;
9: Telefónica I+D, jflp@tid.es; 10: Pirelli Labs, Stefano.Santoni.ex@pirelli.com

Abstract

This paper presents the results of the IST project NOBEL highlighting the evolution of transport networks in Europe in terms of architectures, traffic engineering and economics, control plane and transmission technology issues.

Introduction

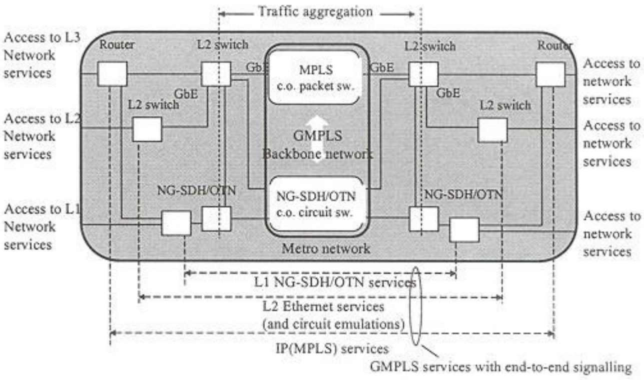
The growth of core transport networks in Europe in the next years will require a full revision of network architectures and technologies, a close integration of IP and transport layers including advanced Control Plane (CP) interworking, and an easy, automated management of optical circuits for fast provisioning and restoration. The IST Integrated Project NOBEL "Next generation Optical network for Broadband European Leadership" has addressed these topics exploiting the knowledge and experience of the partners: Telecom Italia, T-Systems, Telefonica, France Telecom, British Telecom, Telia-Sonera, Telenor, Alcatel, Cisco, Ericsson, ACREO, Lucent Technologies, Marconi, Pirelli Labs, Siemens, AGH, CTTC, FhG/HHI, IBBT/IMEC, ICCS/NTUA, Politecnico of Milano, Scuola Superiore S. Anna, UCL, University of Budapest, University of Stuttgart, UPC, INFN/CNAF. The scope of this paper is to present the project results after one and half year of work.

Network architectures and evolution scenarios

NOBEL has studied and proposed three basic network scenarios for the short-, medium-, long- and extended long-term evolution:

- short-term: based on IP/MPLS and Ethernet, NG-SDH and OTH with some ASON/GMPLS functions;
- medium-term: again based on IP/MPLS and Ethernet, NG-SDH, OTH, OTN with enhanced ASON/GMPLS functions and partial vertical integration;
- long-term scenario based on GMPLS with a peer-to-peer model for a vertical/horizontal integration;
- an extended long-term scenario with the introduction of burst switching network solutions is also under study.

For all these network scenarios, NOBEL is working to optimize the distribution of signaling, routing and switching functionalities and technologies among the two basic network segments (core and metro) in order to meet the emerging requirements whilst reducing CAPEX and OPEX. A schematic representation of the network structure and services, related to long-term scenario, is shown in the next picture.

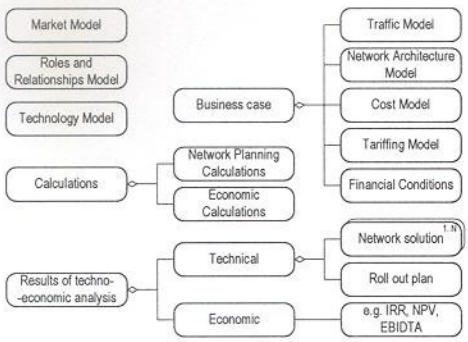


Functional of the network in a long-term scenario

As a first step, NOBEL has studied the main emerging customer applications (multimedia, storage, data and computing grid) in order to identify the main quality parameters required (amount of bandwidth, latency, jitter, availability, etc.). Next, NOBEL has identified network services that can meet the requirements of these customer applications. The main conclusion is that a multi-service circuit-switched and packet-switched network, providing both connection oriented and connectionless connectivity is required, and the following groups of network services have to be offered: Public IP, Business IP, and Virtual Private Networks (VPN) at layer 3, 2, and 1. The final activity will be the definition of design rules for next generation transport networks supporting new broadband network services.

Network cost optimization, Traffic Engineering and resilience strategies

The introduction of a new technology has always a direct influence into the network costs in order to reduce the Operational Expenditures (OPEX) and trying to minimize (or at least to make more efficient) the investments (CAPEX). In addition to this, it has also an impact into the Information Society deployment. Based on the evolutionary scenarios and drivers previously identified some techno-economic case studies have been developed (for example about network planning and dimensioning issues, economic opportunities and costs analysis), following a methodology that help us to recognize and identify what are the NOBEL concepts that should be redefined and what should be well-established due to their validity.



Elements of techno-economic analysis

Another important aspect for the studies is the inputs from the Traffic Engineering (TE) and Resilience Strategies activities carried out in NOBEL. Within TE activities first we have defined QoS aspects to support different applications and services with different requirements and expectations towards the OTN. Also the definition of Quality of Resilience (QoR) and its relationship with QoS has been provided. Secondly it has been investigated solutions for route management in network design and in network operation phase, focusing the results in:

- Routing information inaccuracy for multi-layer networks
- Information exchange strategies for intra- and inter-domain routing
- Evaluation of prediction-based routing
- Evaluation of multicast solution

Other results come from the TMCM (Traffic Measurement, Characterization and Modeling) activity which provides models for evaluation and network planning. Some results are:

- Workload and critical time-scale analysis
- P2P and application characterization
- Studies on SNMP traces
- Multi-layer Networks: Dimensioning & effective bandwidth

With respect to resilience strategies the project aims at providing solutions for multiple QoR classes in single and multi-layer networks. This task is tackled by five study groups, focusing on TE & resilience, and multi-service/multi-layer/multi-domain Resilience issues.

The role of Optical Packet and Burst Switching in future transport networks

Advanced packet and burst switching techniques are considered as long term evolution steps towards new optical broadband core and metro networks adapted to the dominating burst/packet traffic, mainly caused by IP based services. Novel optical network and node architectures to cope with the required flexibility, scalability, quality and reliability for data centric protocols are being developed. A first tentative set of evolution scenarios derived from these architectures respecting the expected traffic profiles evolution and the roadmaps of electronic and optical technologies are available. The first specifications of hybrid opto-electronic burst/packet switching nodes have been elaborated and related studies on dimensioning, benchmarking and feasibility assessments are under way, first results showing clear advantages for burst/packet networks. The specific requirements of burst/packet switching techniques in terms of technologies lead to studies to assess both electronic and optical technologies for finding the optimal balance of optics and electronics to achieve best performance at lowest cost. In this respect, the potential of exploiting transparent optical wavelength/ burst/packet switching to reduce repeated O/E/O conversions is an important cornerstone. The introduction of burst/packet switching techniques into future multi-layer transport networks featuring an integrated CP most probably based on GMPLS will require novel CP and Management Plane functions specific for burst/packet techniques. Special emphasis is to be put on configuration management (bandwidth management, routing), fault management (protection, restoration) and performance management functions (burst/packet network monitoring). One of the key requirements for the target network architectures is the provisioning of end-to-end Quality-of-Service. A number of aspects very specific for burst/packet switching networks need to be covered to enable end-to-end QoS by novel principles and protocols for reservation and allocation of bandwidth (together with service and priority classes), for the related signaling in the burst/packet layer and for the necessary access control and fairness mechanisms to handle bursty and asynchronous traffic. Draft algorithms and protocols are part of the documents to be issued by the project. A continuous assessment of existing and upcoming standardization approaches is performed with respect to possibly required extensions allowing the smooth introduction of burst/packet switching techniques into existing networks and to open the evolution paths towards future hybrid circuit/packet switched network architectures.

Enhancing functions of control and management plane

It is one of the main objectives of NOBEL to design and validate the target architecture for evolutionary multi-service, multi-layer, and multi-domain core and metro networks. NOBEL proposes and analyzes various strategies for integrating network management and control solutions [1]. The investigated approaches are taking account of the requirements for vertical interworking between network layers, and the horizontal collaboration between different network segments and domains.

Horizontal collaboration relates to end-to-end networking in heterogeneous network environments. Hereby, each network element includes one or several common switching layers (data planes). The CP topology extends over several partitions (routing systems) which can be either areas or autonomous systems. Enhancements to the CP are defined that allow seamless collaboration, for instance, between IP/MPLS and GMPLS-controlled transport layers. The vertical integration of network layers driven by the CP allows collaborative mechanisms of multiple data planes. A single GMPLS CP instance with unified (end-to-end) signaling and integrated routing controls resource provisioning and recovery in multilayer networks. A particular attention is brought on the network control integration of IP/Ethernet (Layer 2) switching. This vertically integrated approach builds the basis for unified TE [2], where the different network layers are viewed as a whole. In addition the work covers network control and management aspects of optical transparency. The final goal is to identify the main integrated control, end-to-end operation and management functions required, and to derive a solution capable of managing and controlling the dynamic provisioning of end-to-end broadband services, and to propose functionality needed in the network for enhanced service capability support, such as for VPNs with various implementation options, e.g., Layer 1, Layer 2, and Layer 3 VPNs. Special attention is paid to the distribution of service supportive functionality between network control and management, and to the suitability of a distributed implementation of the CP functions for different ASON/GMPLS network use cases. Another important aspect relates to the cooperative mechanisms of the management and CP in the network. NOBEL is working on the definition of a NOBEL information model (IM) for the interface between the Network Management System and the Element Management (Sub-)System. Policy-based management is used for improving TE functionality of the CP [3]. Finally, NOBEL will elaborate migration strategies for simplified legacy and new network architectures based on packet and circuit switching capabilities.

Multi-service node architectures

One of the main objectives of the project is the identification and evaluation of multi-service/multi-layer node architectures (packets/ circuits/optics) for metro & core networks, the requirement definition for adaptive transport & flexible client interfaces and the prototype realization of selected node and interface functions. To fulfill these objectives the challenges to solve are with respect to the node architectures, the definition of a modular, highly scalable and cost-effective architecture with an electrical plane optimized for the expected data-centric traffic in the future. These nodes have to support "Carrier-class" data transport of services as defined by the network architectures working groups. With respect to the interfaces, additionally challenging goals are the robustness and adaptation to the transmission impairments of the optical plane and the flexibility to the protocols used at the client side.

Whilst in the first year of the project an exhaustive requirement definition of the interfaces and specification of the node architectures have been delivered, experimental verifications of selected node features are in the focus of the work in year 2. For instance new concepts on link stabilization methods [4] have experimentally proven to be suitable to suppress impairments transferred to joint and disjoint light-paths due to both power transient excursions, and spectral changes in case of a fiber break. Advanced modulation formats together with equalization techniques are part of the adaptive transport interface tests, which have been evaluated in respect to their tolerance to linear and non-linear transmission impairments. Another topic is a prototype implementation of selected features of a next generation G.709 frame switch. Here a test-board has been developed and evaluated. Apart from that, also carrier class layer network features like OAM and resilience issues and experiments on tunable dispersion compensators for 40 Gbit/s and optical wavelength converters/regenerators [5] are covered by the activities.

Although the focus is in year 2 on experiments, there is also theoretical work done with respect to the multi-layer/multi-service node architectures. On the one hand this includes pre-work for the experiments like e.g. simulations on advanced modulation formats [6] or studies on implementation issues of the G.709 frame switch, but also further elaborations on e.g. optical wavelength converters/ regenerators and optical bypass architectures are performed. These architectures are for instance compared with respect to their performance or costs. Other topics are the study on automatic bandwidth control with LCAS and GFP or the matching of network modes to the services and their impact on e.g. multi-layer resilience strategies.

Physical layer challenges

In order to guarantee the transport of the data in the above presented concepts, technology and transmission aspects of the optical network architectures (physical layer) are addressed. The objectives are to identify and specify main building blocks of the optical network architectures defined in NOBEL and modeling and simulation of light paths to derive design rules for optically transparent domains and path computation for constraints based routing.

The investigations started out from the currently deployed networks, which are in their majority either static point-to-point WDM links (with some OADM functionality) or SDH/Sonet based rings with electronic add-/drop functionality.

Activities were carried out to define models and run simulations on the performance of building blocks in optical networks. The results were used to identify most suitable modulation formats and compensation strategies against performance impacting functionality in transparent optical networks with respect to cost, distance, and robustness for different network segments (i.e. core, metro, regional). The concepts were evaluated against common performance criteria like baseline OSNR and Q-factor penalty.

These results were combined into light path design rules, which can be adapted to the different needs regarding the size of the network and the expected traffic. During the design phase, i.e. before deployment and operation, complex evaluations between different performance trade-offs can be performed in order to find an optimum placement of equipment within the network. For this purpose full wavelength assignment is carried out for different reference networks together with estimated traffic growth scenarios. Once the network is defined, simplified light path descriptions are used for constraint based routing under dynamic load conditions. Both phases are discussed in more detail in [7].

Combination of the above mentioned network modeling techniques for the design phase together with physical layer impairments based path computation algorithms during the operation shall allow to specify next generation optical networks to provide cost efficient broadband transport capacity, adapted to the needs in metro or core application.

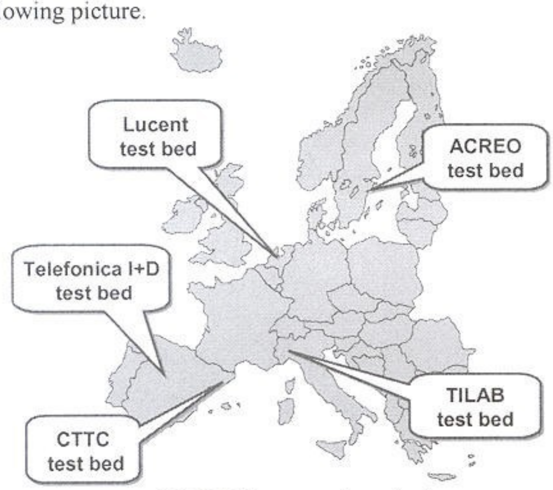
Based on the optimized network architectures and the building blocks utilized to set-up the light paths, a cost comparison study is applied finally, targeting to identify pros and cons for various levels of optical transparency in network segments compared to opaque solutions.

In order to enable these transparent optical networks the following components have been identified to be essential: optical switches for ROADMs and OXCs, tunable lasers and filters, amplifier solutions reducing the problem of transients (see previous section) and optical performance monitoring (OPM). Requirements for the components in transparent optical networks have been established and a market scan for currently available components has been performed.

Also the aspect of future proof systems [8] and components for optical burst and packet switched networks has been addressed [9].

Integrated test-bed and experiments

The major results coming from theoretical studies and from implementation activities within NOBEL, will be assessed by means of integrated experiments. They take place in an integrated test-bed that has been developed during the project, and that is schematically shown in the following picture.



NOBEL integrated test bed

The test-bed is the basis where all the equipment, subsystems and emulators realized in the project are integrated and the experiments on the advanced functionalities are defined, specified and carried out. Among the functionalities that will be demonstrated by means of such a test-bed, the following are of paramount importance:

- intra- and inter-domain ASON/GMPLS advanced functionalities dealing also with transmission aspects.
- multi-layer resilience strategies in a multi-domain environment.
- management and control functionality.
- multi/service nodes capabilities.

Theses activities require a strict coordination among all the topics studied in the project. The definition of the experiment configurations and of the related systems requirements (equipment, subsystems and emulators) have been analyzed in the first stage of the project. Results on experiments currently being performed will be presented at the conference.

Conclusions

The IST NOBEL project has developed a comprehensive vision of core transport networks in Europe in the next decade. The concepts developed in NOBEL will be further enhanced and experimentally demonstrated in a second phase of the project that is currently under evaluation by the European Commission. For additional information on the project please visit: www.ist-nobel.org.

References

1. B. Berde et al., ONDM2005, Feb. 2005, Milan, Italy.
2. M. Vigoureux et al., to appear in IEEE Communication Magazine, July 2005.
3. H. Lønsethagen, B. Berde, NOC2004, June 2004, Eindhoven, The Netherlands.
4. E. Ciaramella , submitted to ECOC'05.
5. G. Contestabile et al. submitted to PTL.
6. H. Griesser et al, submitted to ECOC'05.
7. D.A. Schupke et al. Proc NOC2005, London, pp139.
8. G. Lehmann et al. Proc. OECC, Seoul, 6B4-1.
9. L. Meflah et al. Proc. NOC2005, London, pp. 554